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## On the Origin of Sulfur

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**Abstract.** We present our work on the halo evolution of sulfur, based on observations of the S I lines around 9220 Å for ten stars for which the S abundance was obtained previously from much weaker S I lines at 8694 Å. We cannot confirm the rise and the high [S/Fe] abundances for low [Fe/H], as claimed in the literature from analysis of the 8694 Å lines. The reasons for claims of an increase in [S/Fe] with decreasing [Fe/H] are probably twofold: uncertainties in the measurements of the weak 8694 Å lines, and systematic errors in metallicity determinations from Fe I lines. The near-infrared sulfur triplet at 9212.9, 9228.1, and 9237.5 Å are preferred for an abundance analysis of sulfur for metal-poor stars. Our work was presented in full by Ryde & Lambert (2004).

There has recently been a debate in the literature on the chemical evolution of sulfur in the halo phase of the Milky Way ( $[\text{Fe}/\text{H}] \leq -1$ ). Israelian & Rebolo (2001) and Takada-Hidai et al. (2002) claim a monotonic rise in [S/Fe] for decreasing [Fe/H] based on an analysis using weak sulfur lines at 8694 Å measured in spectra of approximately ten stars each. This rise has consequences for our understanding of the sites of formation of sulfur in the Universe.

Is there a rise or not? In order to answer this question, we have reinvestigated ten of the stars examined previously, by analysing the infrared triplet lines of neutral sulfur at 9220 Å instead of the weaker 8694 Å lines used before. The lines are indicated in the Grotrian diagram shown in Figure 1. The lower levels of the 8694 Å lines are the upper levels of the 9220 Å lines and hence the excitation potential difference is 1.34 eV.

We observed the stars with the 2dCoudé spectrometer (Tull et al. 1995) at McDonald Observatory in 2001. Our stars are a mix of dwarfs and giants spanning a temperatures range of 4200 – 6300 K, and a metallicity range from  $[\text{Fe}/\text{H}] = -0.7$  down to  $[\text{Fe}/\text{H}] = -2.9$ . Exposure times ranged from half-an-hour to three hours per star. In our analysis, we use the model atmosphere parameters used by Israelian & Rebolo (2001) and Takada-Hidai et al. (2002) with the exception that the metallicity is re-determined from Fe II lines, which are not much affected by non-LTE effects, instead of the more uncertain determination of the metallicity based on an non-LTE analysis of Fe I lines.

Figure 1. Part of the Grotrian diagram of sulfur is shown with a few transitions indicated. The transitions in black indicate the IR triplet lines at 9212.9, 9228.1, and 9237.5 Å and the weaker 8694 Å lines used by Israelian & Rebolo (2001) and Takada-Hidai et al. (2002). The Figure is based on the Grotrian diagrams in Bashkin & Stoner (1978).

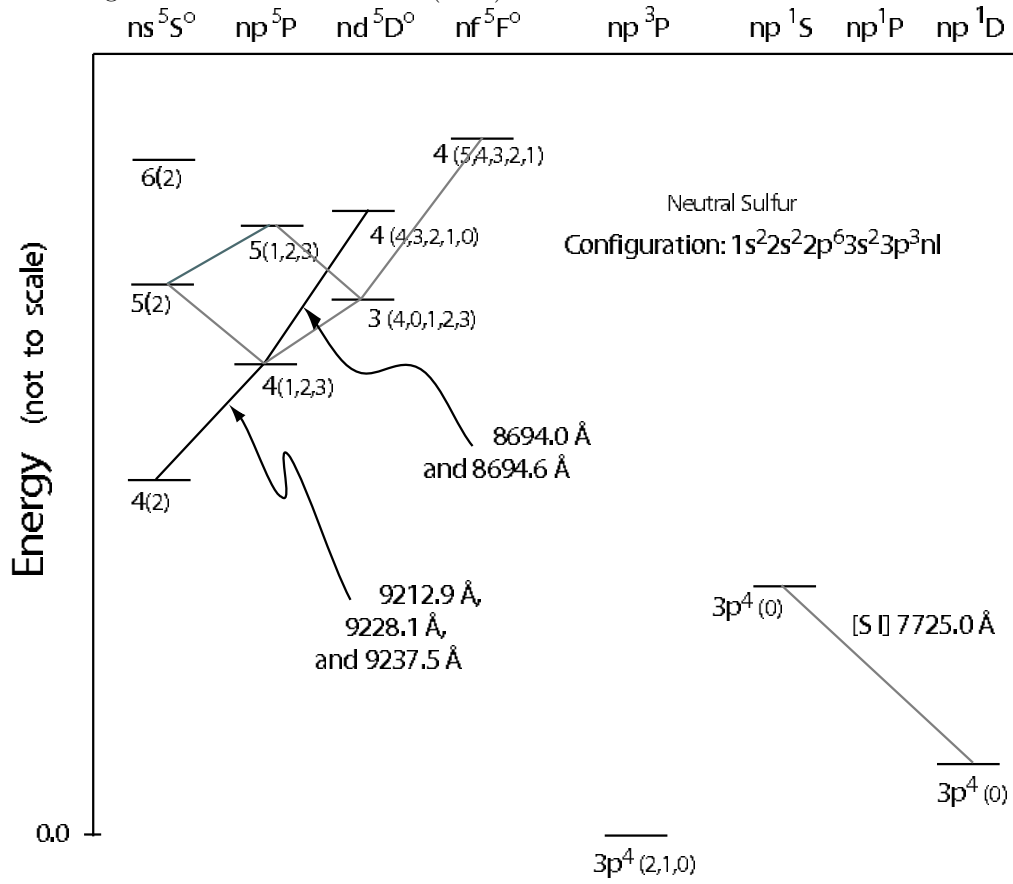


Figure 2. The chemical evolution of sulfur. Our new measurements are shown by star symbols. These are connected to the earlier observations, claiming a rise. The measurements of Nissen et al. (2004) and Chen et al. (2002) are also shown.

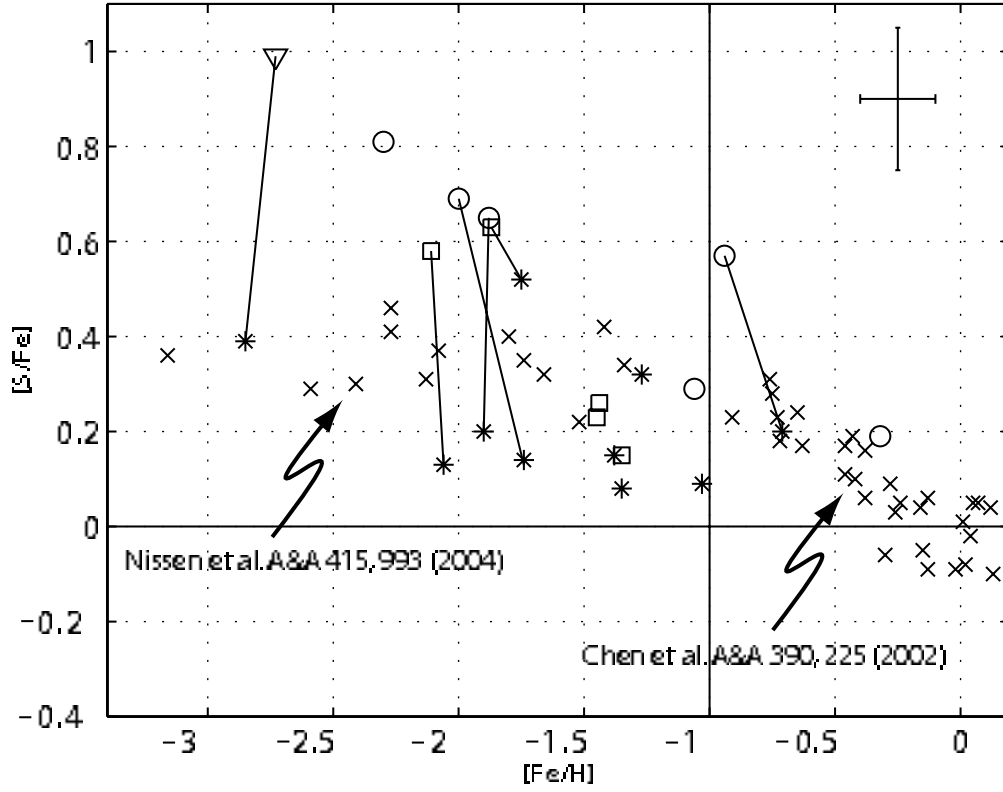
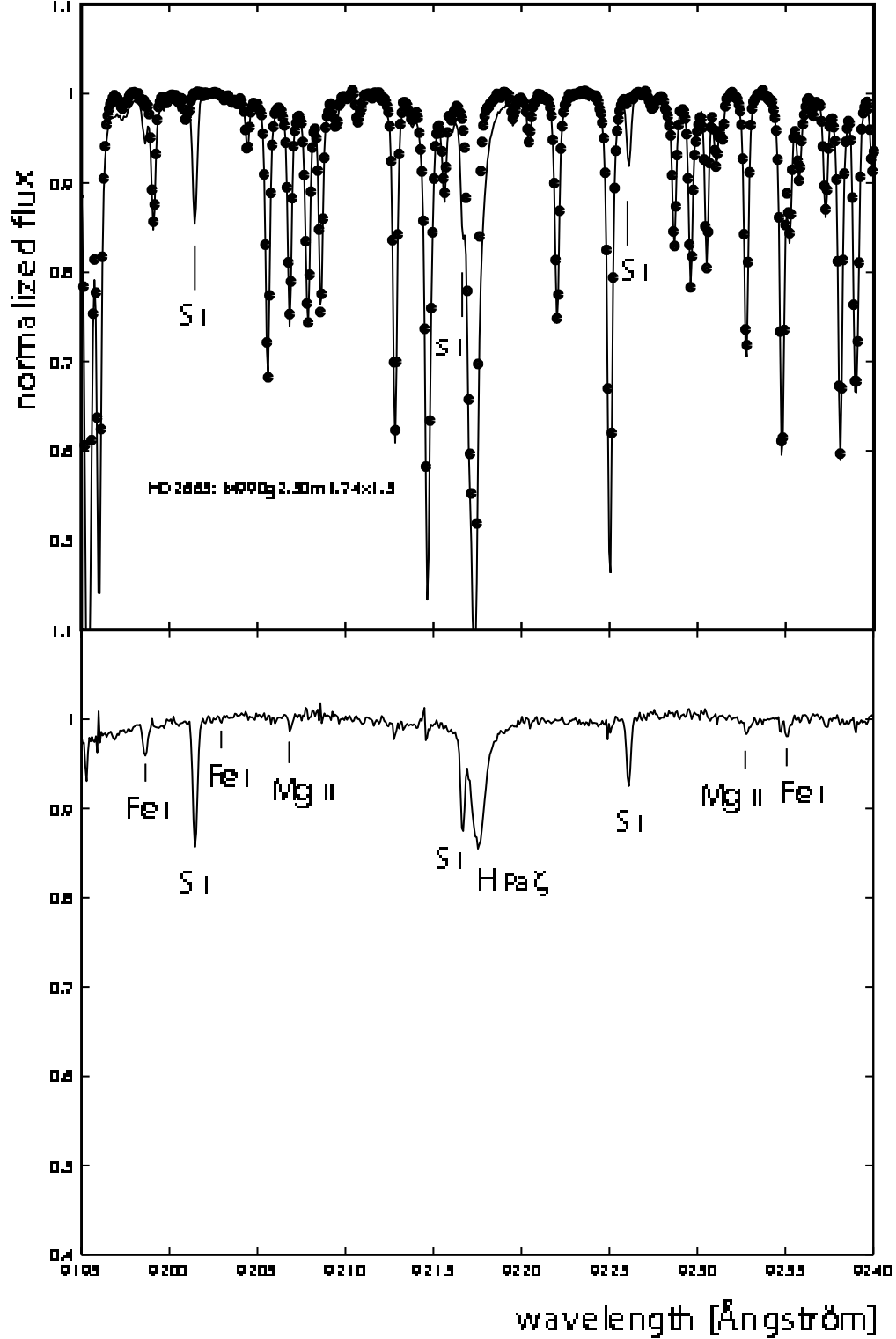


Figure 3. Example of our observations. The telluric lines in the spectrum above are nicely eliminated in the final one below



We do not confirm the rise in  $[S/Fe]$  with decreasing  $[Fe/H]$  in the halo phase. Instead, we confirm that  $[S/Fe]$  attains a plateau for the halo phase of the Galaxy, also shown by Nissen et al. (2004), see Figure 2. Thus, sulfur behaves similarly to alpha elements (e.g., Mg, Si, and Ca), indicating that the primary source for sulfur atoms in the Universe is Supernovae Type II explosions.

A significant advantage of the near-IR lines over the 8694 Å lines in the study of halo stars is their factor of ten larger equivalent widths. An apparent disadvantage of the near-IR lines is the ubiquitous telluric water-vapor lines in this region. By observing a rapidly-rotating hot star at a similar air mass to each halo star observation, the water vapor lines may be divided out, as shown in Figure 3.

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